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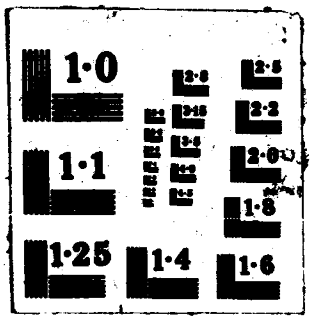
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TECHNICAL NOTE

MRL-TN-519

THE WAFTER : A VERSATILE WEAR AND FRICTION TESTER

P. Jewsbury

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THE WAFTER : A VERSATILE WEAR AND FRICTION TESTER

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ABSTRACT

This report describes the design and use of a pins-on-disc wear and friction testing machine which has been constructed for use by the Wear Technology Group. The tester is capable of assessing sliding wear at speeds up to 4 m/sec and loads up to 40 N. During a wear run the friction and contact resistance are constantly monitored giving a clear picture of the condition of the surfaces.

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LIST OF VARIABLES

Name	Value	Description
C	.33F	Averaging capacitor used in resistance measurements
d	d_i, d_o	Diameter of track traversed by pins
d_i	112.15 mm	Diameter of the inner track on disc
d_o	143.15 mm	Diameter of the outer track on disc
f	0-500 RPM	Rotational speed in rev/min at which pins are driven
i	0-1 mA	Current in circuit of resistance device
ℓ	1-4 kg	Combined load applied to system of two pins
ℓ_c	1 kg	Calibration weight used to calibrate friction values
q(t)	CV(t)	Charge on averaging capacitor
R(t)	0-10 kΩ	Contact resistance between pins and disc
s	98 mm	Distance of point of application of calibration force from plate centre.
t	105-115 mm	Distance of strain gauge from plate centre
u	0-199.9	Reading on digital friction display during operation
u_A	0-199.9	Reading on digital friction display when no force on load cell
u_B	0-199.9	Reading on digital friction display when light contact on load cell
u_C	0-199.9	Reading on digital friction display when calibration load applied
v	0-4 m/s	Sliding speed of pins on disc
V(t)	iR(t)	Voltage applied across pins and disc
μ	$2\ell_c s(u-u_b)/[\ell d(u_c-u_b)]$	Coefficient of sliding friction

THE WAFTER : A VERSATILE WEAR AND FRICTION TESTER

1. INTRODUCTION

A wear and friction tester, known as the WAFTER, has been designed and built within the Wear Technology Group. This machine allows the sliding wear rate of two metallic pins run against a wear plate to be assessed under a variety of conditions.

The design incorporates several novel features (figure 1). It can assess the sliding wear under lubricated or unlubricated conditions. To minimize the extent of lubricant starvation from centrifugal forces, it was decided that the pins would be driven around the plate rather than the conventional gramophone style arrangement of spinning the plate under a pin. For stability two pins, rather than one pin, are driven around the base plate. The two pins are regarded as a single wear body and are symmetrically positioned either side of the drive shaft. This ensures that the machine can operate up to very high loads (40 N) and speeds (4 m/sec). Thus the important transition from mild to severe wear in steels can be extensively studied.

The literature contains many different types of wear testing rig, pin-on-disc, crossed cylinder, pin-on-flat, flat-on-flat, disc-on-disc etc. Each represents a different wear situation. In interpreting the results of pin-on-disc machines it is important to realize that although the wear surface of a pin is in continual contact with the plate, each part of the wear surface of the plate is only in intermittent contact with a pin. Thus a pin will run hotter than the plate particularly when there is a high contact resistance.

The purpose of this report is to describe the design features and principles of the WAFTER and its operating procedure.

2. DESCRIPTION

Two identical wear pins (figure 2) are held in an assembly which is free to move vertically only. The weight of this assembly (currently 1.223 kg) and applied weights, which sit on the cross connecting bar, bear down on the two wear pins. The pins present a combined apparent contact area of .633 cm^2 with the wear plate (figure 3) which is held firmly in the lubricant tray by four screws. This tray is suspended in a near frictionless manner by three equispaced piano wires. The tray is prevented from moving in a translational manner, in the horizontal plane, by three equispaced roller bearings which leave the tray free to rotate. The assembly containing the pins is spun around at rotational speeds up to 500 RPM recorded by a tachometer. To provide some isolation from motor vibration this assembly is belt driven. The equal and opposite sliding frictional forces on pins and plate are monitored by a strain gauge which prevents the tray from rotating. A pulley cable can be attached to the tray to enable the strain gauge to be calibrated. The pins can be inserted in one of two positions which correspond to their executing tracks around the disk of diameters 112.15 or 143.15 mm. Thus in the outer track the sliding speed is

$$v = 449.7 \times f \text{ mm/min}$$

and in the inner track the sliding speed is

$$v = 352.3 \times f \text{ mm/min}$$

where f is the rotational speed in RPM.

The pins are designed with a shoulder so that they sit firmly within their holders, yet are easily removed even when there is significant plastic flow to the wear surface.

3. SET-UP PROCEDURE

Before an experimental wear test can be performed the apparatus must be prepared in a careful and consistent manner. This preparation may include alignment of the base plate, insertion of the wear pins, calibration of the monitors.

3.1 Alignment of Wear Plate

Whenever a wear plate is replaced or reinserted in the lubricant tray it should be aligned, as closely as possible, parallel to the horizontal plane defined by the rotation of the cross connecting bar. This is achieved by the following procedure:

1. The bolts holding the three roller bearings, which constrain the tray, and the strain gauge are loosened and these items are moved out of contact with the tray.

2. A micrometer gauge is attached to the front face of the cross connecting bar on the side of the arm stamped with unloaded weight of this assembly. The gauge is set to measure the height of the arm above the wear plate.

3. The three steel suspension wires are adjusted at their top supports so that the micrometer gauge reads the same value (to within .001 inch or 25.4 μm) at the three locations on the plate in line with the suspension wires.

4. The roller bearings are moved so as to be touching the tray and firmly secured using the screws below the table top. Check that the tray cannot move translationally by even a small amount.

3.2 Insertion of Wear Pins

Insertion of the wear pins in the apparatus is a simple operation, however, there are certain ancillary considerations.

1. The wear pins should be washed, dried and individually weighed (at room temperature) to at least .05 mg accuracy.

2. The wear pins may then be inserted in either the inner or outer holes of the pin holders. Both pins must be in corresponding holes. The pin design is such that identification numbers should be clearly visible on the inserted pins. By convention the pin with the larger identification number is placed under the arm of the cross connecting bar which bears the weight stamp. The occurrence of pins on one side systematically wearing more than pins on the other would indicate damage to the pin holding assembly frame.

3. The pin is clamped in place by tightening the nut. Note that the counterbalance head should be positioned directly opposite to the pin so that it remains securely fixed in position.

4. The mercury electrical contact on the central shaft should be checked to ensure that the wire is well immersed in the mercury. The wire can be adjusted or mercury topped up.

3.3 Calibration for friction measurements

Prior to every wear test run, the readings on the strain gauge digital display must be recalibrated. This procedure will also enable the chart recorder to be calibrated.

1. A reading, u_A, on the digital display is taken with the strain gauge free of the lubricant tray.

2. The strain gauge is firmly bolted in position so as to be lightly touching the lubricant tray and preventing its motion. A reading, u_B, on the display (and chart recorder) is taken. This reading must differ from u_A by less than 8 units.

3. The calibration weight, w_c, is suspended from a pulley and a reading u_c on digital display (and chart recorder) is taken. Note that the calibration weight should be gently lowered, dropping it may damage the strain gauge.

4. The calibration weight is removed and the reading u_B is retaken. If the values of u_B differ by more than 5 units,

   (a) apply a little oil to the roller bearings constraining the tray,

   (b) check that the roller bearings are pressing evenly on the tray and are free to move,

   (c) repeat the calibration procedure from the start.

3.4 Calibration for resistance measurements

No calibration is required for the direct meter reading of the average resistance. The average resistance is the value shown on the digital display multiplied by the multiplication factor shown on the ammeter. However, the chart recorder should display a calibration standard in association with each run by using the calibration signals from the average resistance meter (ARM). A description of the ARM is given in Appendix 2. The chart calibration is performed in the following manner:

1. First choose the driving current (multiplication factor) which will be used in the wear tests. The ARM should then be adjusted to supply this current. The normal operational current value is $\frac{1}{2}$ mA (multiplication factor 4). Use a lower current value if the resistance could exceed 8 kΩ.

2. Set the output switch on the ARM to the calibration setting 0 Ω and obtain a trace on the chart recorder, and identify this trace.

3. Then set the switch to either 1 kΩ or 10 kΩ, depending on the magnitude of the contact resistance expected (the 1 kΩ scale would be the natural choice at low speeds and at speeds above the mild to severe wear transition). Again take and identify the trace of this signal.

4. If desirable, adjustments can be made to the chart recorder so that these signals coincide with chart markings. The output switch should then be returned to the load setting.

4. OPERATION

The operation of the equipment is relatively straight forward. This includes controlling the wear conditions and monitoring equipment.

4.1 Wear Run

The set-up procedure should be carried out as described in Section 3. Notes should be taken to record the pin identification numbers, friction calibration readings, initial weights of pins, tracks the pins will slide in etc. A wear test report form (figure 4) can be used for this purpose. Other measurements such as talisurf traces should also be performed. The applied load (which may be zero) is fitted on the cross connecting bar, in two equal amounts above each pin. The power is then applied to the 0.18 kW drive motor and the variable clutch drive is adjusted to give the required rotational speed which is monitored on the tachometer. A digital time switch can be set to automatically stop the experiment at a given time. A typical run time for hard steel surfaces would be seven hours.

During operation both the friction and averaged contact resistance between pins and plate are continuously displayed and a permanent record can be kept on the chart recorder. Slow variations in the frictional force indicate how the surfaces are changing ("wearing in") during the experiment. After the run the pins were reweighed and the pins, plate and debris can be further studied. Although only the combined weight loss of the pins is considered, both pins should lose a similar weight.

A wear test should include many wear runs. The easiest way to ensure that the surfaces are "run-in" is to perform a sequence of wear runs at the same load but steadily increasing the rotational speed by 10 RPM each time.

4.2 ARM Operation

The ARM has three modes of operation 1) calibration 2) monitoring without averaging and 3) monitoring with averaging. The calibration mode is used to send reference signals to the chart record as described in Section 3. When monitoring without averaging is selected, the fluctuating voltage signal which represents the true instantaneous resistance is displayed on a cathode ray oscilloscope. This mode shows the bridging and breaking of asperities but gives no quantitative description of the state of the surfaces or mode of wear. Monitoring with averaging gives a direct measure of metal-to-metal contact. This contact is impeded by oxide build up on the surfaces, oxide debris in the wear track and work hardening. Dramatic changes in the resistance value are a clear signal of a change in wear mode.

The function of the controls and meters on the ARM is shown in figure 5. This figure describes how to set each of the switches for the required mode of operation and no additional information is required.

5. CONCLUSION

This report has described design features and the operation of a pins-on-disc wear and friction testing machine known as the WAFTER. This machine has been operated at loads up to 40 kg and speeds up to 4 m/sec. Thus the wear characteristics of wear resistant coatings or materials can be studied. The monitoring of resistance and friction gives a real-time indication of the state of the surfaces and their wear behaviour.

Using the WAFTER, it is therefore possible to assess sliding wear failure criteria relating either to total material loss or to the transition from mild to severe wear, as well as to study wear mechanisms under controlled conditions.

6. ACKNOWLEDGEMENTS

I would like to greatfully acknowledge the contributions made by I. Downes and G. Zouev to the design and construction of this device.

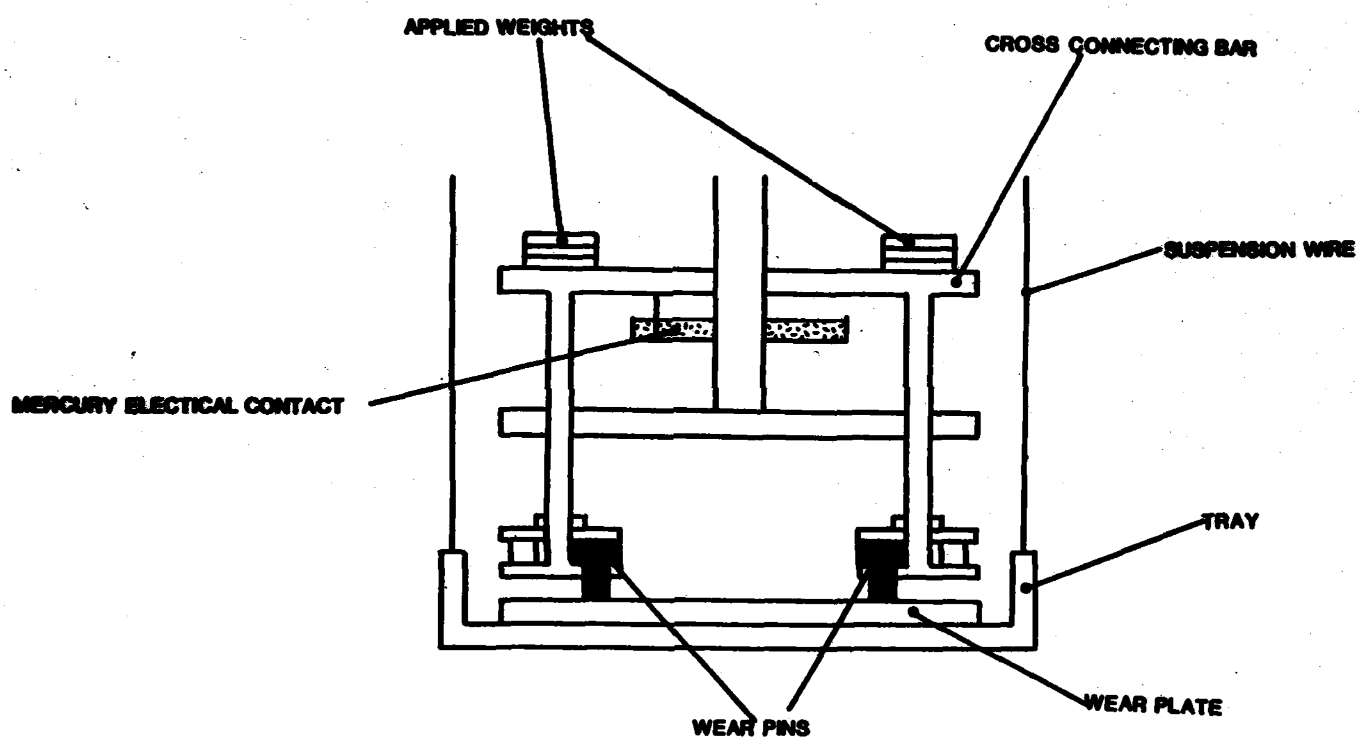


FIGURE 1. Schematic diagram of pins-on-disc wear tester. The two pins are rigidly connected and driven around the stationary plate.

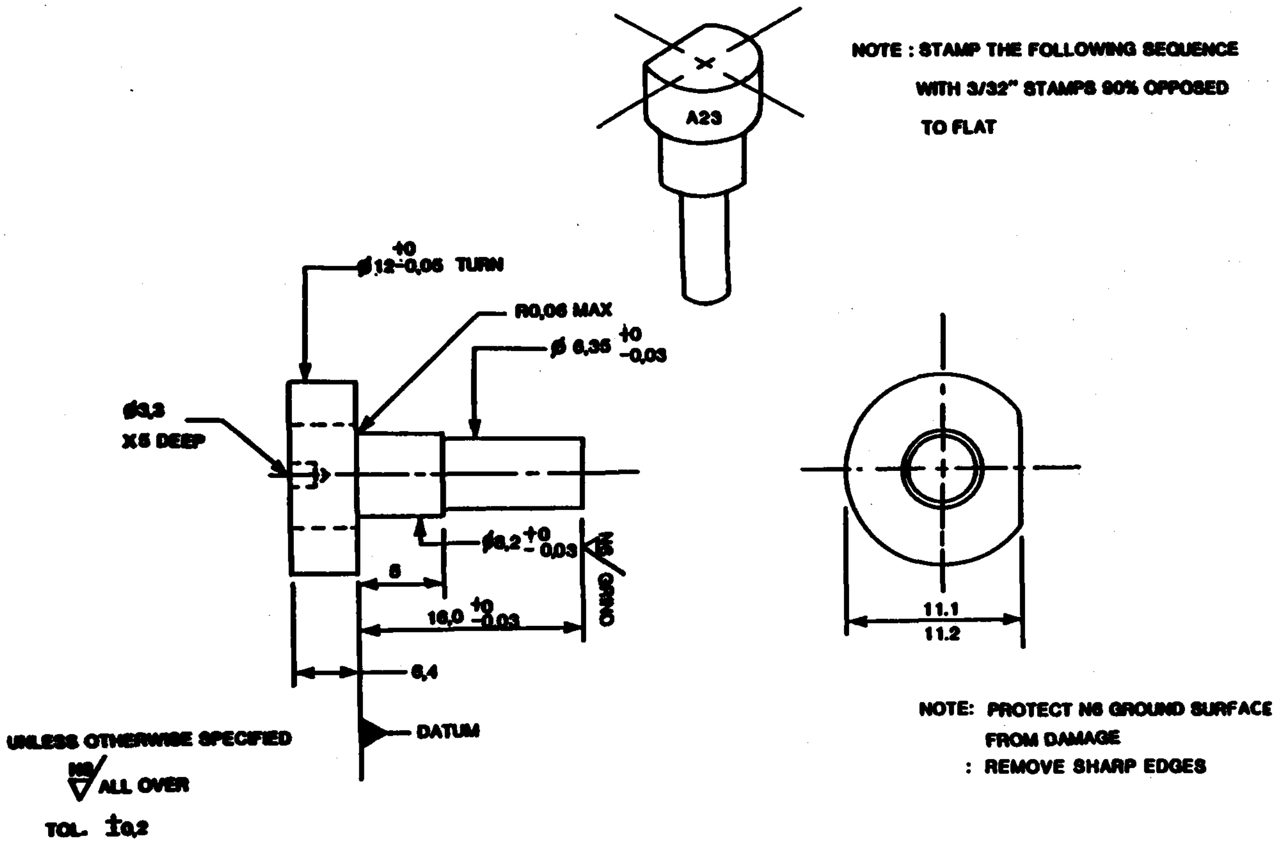


FIGURE 2 Specifications for making wear pins for the WAFTER.

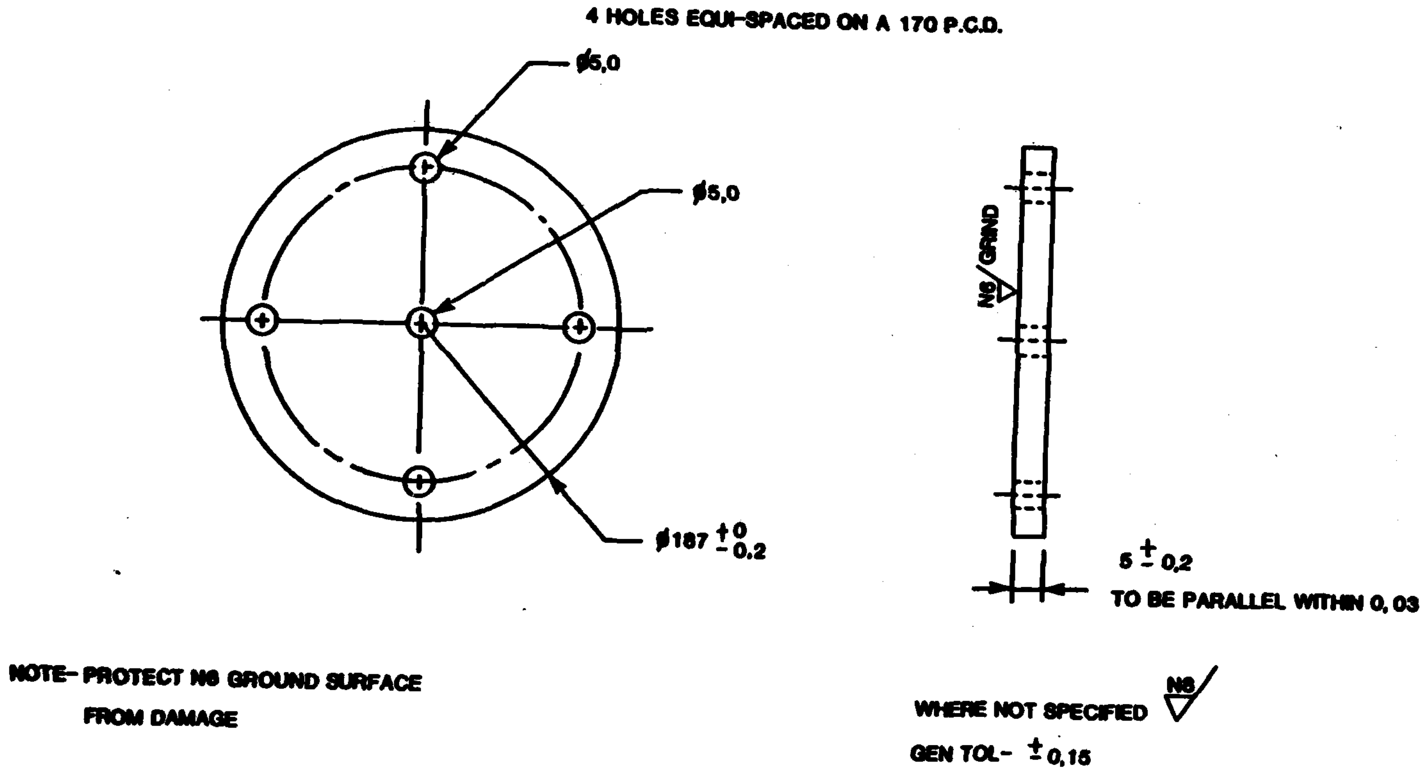


FIGURE 3 Specifications for making a wear plate for the WAFTER.

WAFTER REPORT SHEET

DATE: ________ OPERATOR: ____________ WEAR TEST I.D. ________ WEAR RUN I.D. __________

	PRIOR TO RUN	AFTER RUN
PIN I.D.		
Weight		
W/S Arm Y/N		
CLA		
Other		
Weight Loss	mg	mg

FRICTION CALIBRATION

CALIBRATION WEIGHT

READING u_A

READING u_B

READING u_C

READING u_B

SUMMARY

TOTAL WEIGHT LOSS

DURATION OF TEST

FULL LOAD

SLIDING SPEED

FINAL COEFFICIENT OF FRICTION

FINAL CONTACT RESISTANCE

A.R.M.

CURRENT FACTOR X

CHART 0 1K 10K

RUN

LOAD DEAD-WEIGHT APPLIED

TRACK INNER/OUTER RPM CHART I.D.

PIN STATUS

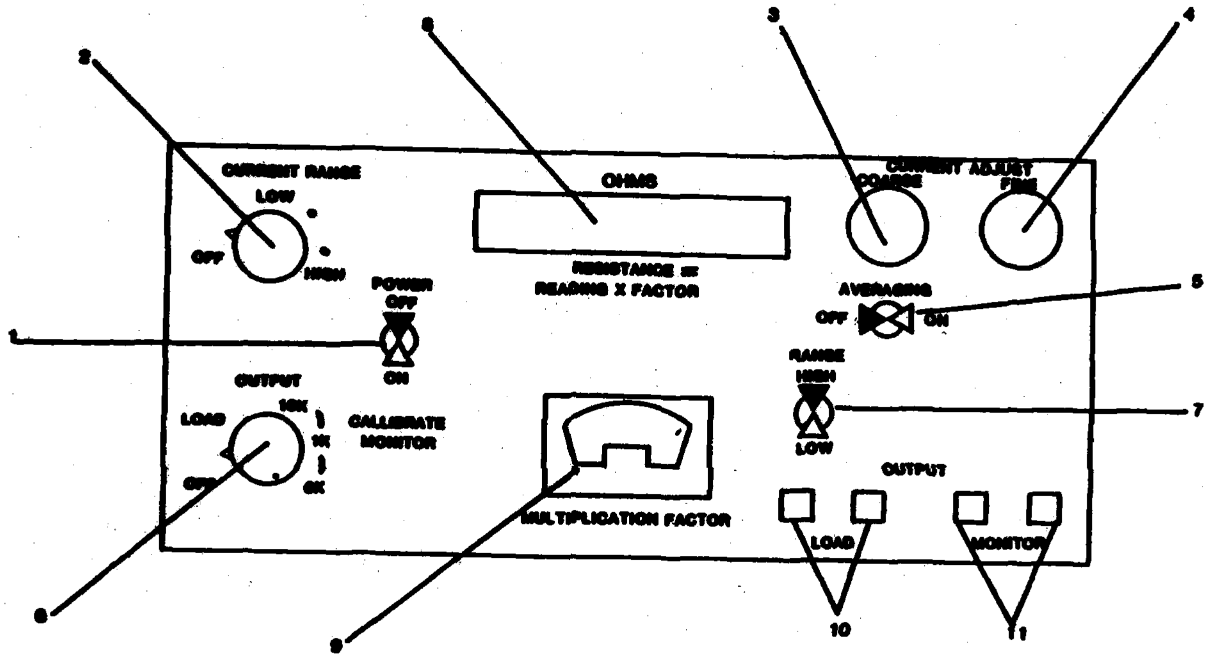
PLATE I.D. PLATE STATUS

START TIME FINISH TIME

REPORT

TIME	RESISTANCE READING	FRICTION READING	COMMENTS

FIGURE 4 Wear test report form.



SWITCHES

1.Mains power on/off
2.Discrete current adjust
3.Continuous coarse current adjust
4.Continuous fine current adjust
5.Signal averaging on/off
6.Select either register load or send calibration signal to monitor (0, 1k or 10k)
7.Select scale for digital display 0–199.9(low) or 0–1999(high)

DISPLAYS

8.LOAD VALUE,reading to be multiplied by factor to give ohms
9.Ammeter displays current set by switches 2,3&4 and gives the multiplication factor for 8 in green

OUTPUTS

10.To pins-on-disc contact
11.To chart recorder

FIGURE 5 *Average resistance meter.*

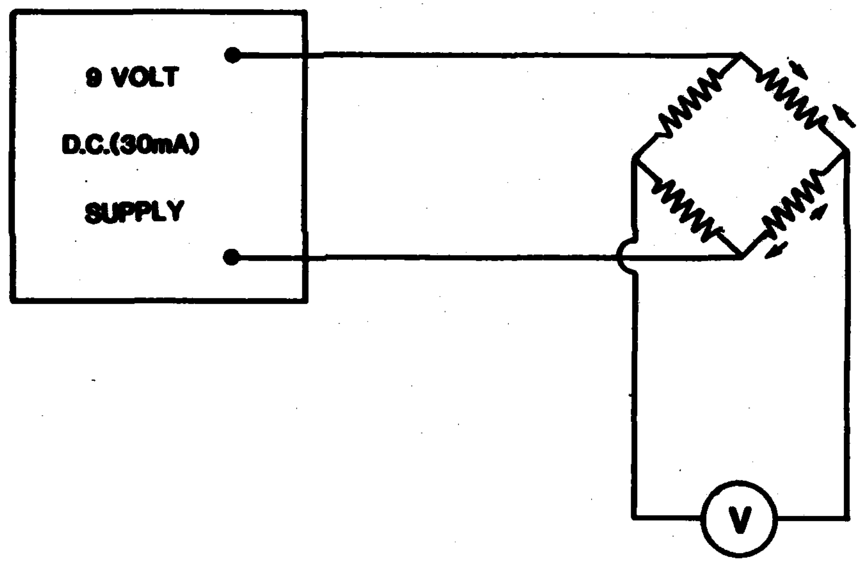


FIGURE 6 Principle of operation of Interface Model MB-5 Minibeam load cell.

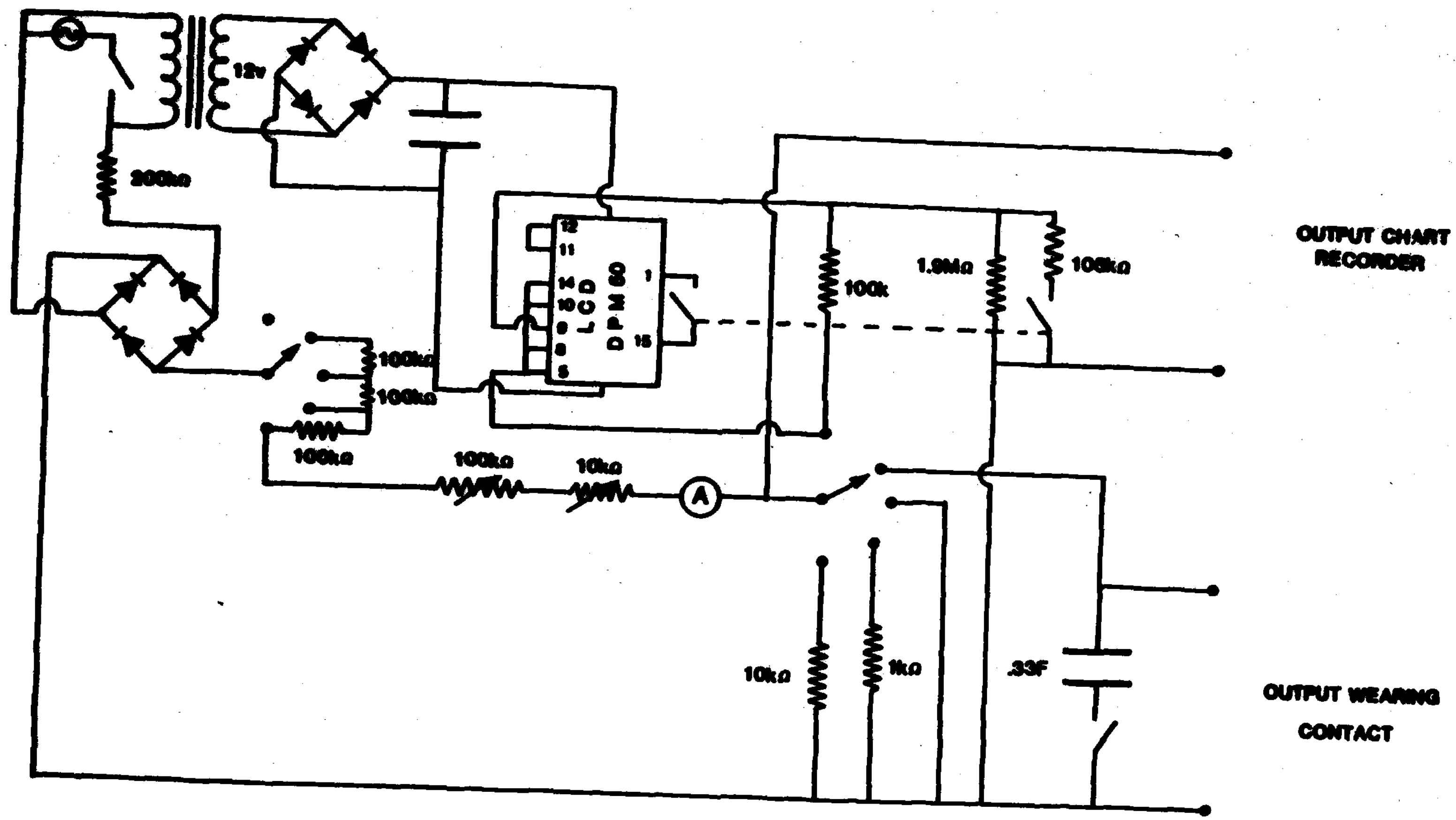


FIGURE 7 Average resistance meter circuit diagram.

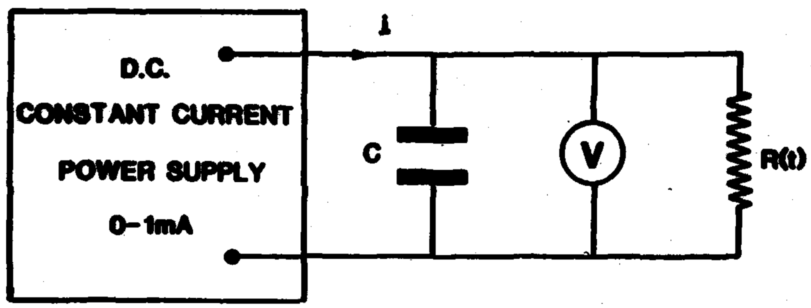


FIGURE 8 Principle of operation of Average Resistance Meter.

APPENDIX 1

MEASUREMENT OF FRICTION COEFFICIENT

A measure of the frictional forces on pins and plate is given by the response of a MB-5 minibeam load cell. This gauge is designed to operate in the temperature regime -18°C to 66°C. It will give a linear response up to an applied force on the gauge of 22.2 N and will undergo irrepairable damage above 33.3 N. The gauge therefore remains in the linear range, provided the coefficient of friction, μ, satisfies

$$\mu < \frac{4.5\ t}{\ell\ d}$$

where ℓ is the total load on the pins in kg, t is the separation of the load cell from the centre of the wear plate and d is the diameter of the wearing track. Conservatively this implies

$$\mu < 3/\ell(\mathrm{kg})$$

The functioning of the force measuring circuitry is shown in figure 6. The strain gauge is a Wheatstone bridge, two elements of which are subjected to strain and vary in resistance. The monitor is essentially a voltmeter but with a zero adjust and an amplification capacity. Readings are sensitive to interference through the power supply from other equipment (particularly power supplies driving unsteady glow discharges).

The strain gauge registers the restraining force on the tray. Since, were it not for the strain gauge the tray would be free to rotate but not translate, the calibration load, ℓ_c, must provide a couple $\ell_c s$. Here s is the distance to the plate centre of the applied calibration force on the tray. Thus within the linear response regime, a display reading, u, corresponds to a coefficient of sliding friction

$$\mu = \frac{2\ \ell_c s}{\ell\ d}\ \frac{u - u_b}{u_c - u_b}\ .$$

APPENDIX 2

AVERAGE RESISTANCE METER

The average resistance meter is a stand alone device that could be used independently of the WAFTER. Therefore detailed information on this device is provided here. The role of the switches and displays is explained in figure 5 and a circuit diagram is presented in figure 7. However, for an explanation of how the device works, refer to figure 8.

The linear first order differential equation describing the variation of the potential, V(t), across the pins/disc junction is

$$\dot{V}(t) + \frac{V(t)}{C\,R(t)} = \frac{i}{C}$$

where i is the supplied d.c. current, C is the average capacitor and R(t) the junction resistance. This has solution

$$V(t) = C' \exp(-p(t)) + \frac{i}{C} \int_0^t dt' \exp\left(p(t') - p(t)\right)$$

where C' is a constant of integration (determined by starting conditions) and

$$p(t) = \frac{1}{C} \int_0^t dt' \frac{1}{R(t')}$$

For large times $t \gg C \langle \frac{1}{R} \rangle^{-1}$ we make the approximation

$$p(t) \simeq \frac{1}{C} \langle \frac{1}{R} \rangle t$$

where brackets < > denote an average. Thus we obtain

$$V(t) \simeq i \langle \frac{1}{R} \rangle^{-1}$$

i.e. the voltage is proportional to the reciprocal of the average conductance.

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